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PRODUCTION, MANIPULATION, AND APPLICATIONS OF ULTRACOLD POLAR MOLECULE

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Final Report

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14. ABSTRACT

The development of techniques for producing, trapping, and detecting ultracold polar molecules, including “assembly” of molecules from ultracold atoms and the direct cooling of both neutral and ionized molecules is the first theme of the project. The second is controlling the arising interactions using external electromagnetic fields, thus manipulating collisions and chemical reactions, and engineering molecule-based quantum information. The third is development of applications for ultracold polar molecules, such as technologies for high-resolution spectroscopy, engineering of highly-correlated interacting many-body systems. The outcome includes the first steps towards quantum-degenerate gases of polar molecules for a chemically diverse range of species, which have been trapped and cooled to the ultracold regime. Novel types of collisional and chemical-reactive behavior were observed, controlled, and understood theoretically. The first implementations of quantum information encoding and processing with polar molecule qubits were demonstrated, and improved schemes for large-scale systems are being devised. Novel features of many-body systems of strongly-interacting polar molecules were analyzed, and the details of molecular structure were measured and applied.

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Main accomplishments:

Publications

Total: 130, of those: 8 Nature, 1 Science, 27 Phys. Rev. Lett.

Milestones

The vast majority of milestones were reached and often surpassed, such as laser cooling, building a MOT, and buffer gas cooling, which was done for a larger variety of molecules and to a larger extend than originally proposed. The exception is the full cooling of $SrCl^+$ to $<$ 1 mK, only part of this milestone was reached. For the theoretical projects, many additional projects were added to the MURI, and in some cases, the experiments were carried out on different molecules than originally stated (e.g., laser cooling and trapping in a MOT).

Summary of most important research outcomes

After the very first production of polar molecules in their absolute ground states, laser cooling and trapping (e.g., in a magneto-optical trap or MOT) and evaporative cooling was deemed close to impossible by many scientists prior to this MURI, as was reliable cooling into a complete molecular ground state. Nevertheless, all three were accomplished in our research. The first laser cooling, the first MOTs, the first ground state cooling , and the lowest external and internal temperatures were accomplished in those five years. These methods are, however, not universal to all molecules and not yet feasible for all labs, thus, in addition, we have developed simpler and more versatile techniques to reach the same goals, with less dramatic results but results that are potentially more important for future developments. This includes, most notably, the development of sophisticated buffer gas sources that allow for high-phase-space density ultracold samples of a wide variety of molecules. These techniques have now literally been distributed as the new gold standard to labs over the whole world. Also, molecule production with more specialized focus plays an important role, such as the (more involved) production of NaLi, the smallest polar molecule, which promises special properties, and the benchmark experiments on K and Rb in more modest laboratory settings that will be important for a wider group of scientists in the decades to come. This also includes the first studies of on-chip molecular ions.

Ultracold chemical reactions have been, theoretically and experimentally, been studied for the first time (and mostly exclusively) in this MURI group. A major part of present knowledge about controlling ultracold chemical reactions using electromagnetic fields, coherent methods, geometries, and other methods, in particular to study which channels for

which classes of molecules can be modified by different methods. The challenge we faced in this part of the project is the pure multitude of different possibilities, such that classification for certain chemical processes in this regime and how to understand and manipulate them was a major product of this MURI. This, in particular, includes also the new phenomenon of *sticking* that is relevant only to ultracold temperatures.

Suggestions for applications for ultracold molecules were deliberately kept somewhat vague in the proposal, since applications typically come out of special findings during the research and are often hard to predict. Thus, the outcome in this category of our MURI is a combination of the predicted, most notably a comprehensive study of the many-body physics of interacting dipoles in optical lattices theoretically and first major success to experimentally implement those. It is important to note that this touched (and often initialized) virtually all areas of recent interest in the theory of strongly interacting systems, such as magnetism, Majorana Fermions, many-body localization, to name just a few. In addition, there has been a multitude of less predictable outcomes: special quantum information processing schemes, uses of entanglement such a spin-squeezing for better quantum measurements, and the foundations of a method to distinguish molecules of opposite chirality (the method itself is not part of this MURI). Among the applications belong also the proposals and experimental implementation of improvement of detection methods.

Itemized list of accomplishments:

Production, cooling, trapping, detection, and spectroscopy

- Buffer gas sources

  The Doyle group developed and demonstrated a novel approach to magnetic trapping of a wide variety of molecules using a two-stage buffer gas beam source in conjunction with optical loading into a magnetic trap. Our two-stage buffer-gas source produces molecules slow enough so that simply through the interaction of the molecules with the fringing fields of the trap, they can be slowed to trappable velocities. In order to load irreversibly, two lasers are used. The wavelengths are set to pump the molecules from low-field seeing states to high-field-seeking states (and back) at key points in the magnetic field. The molecules spontaneously emit photons as they are pumped, providing the irreversible steps. We fully modeled this approach for CaF and CaH and then implemented the procedure, verifying our quantitative model. We also did the same trapping with an atom, potassium, trapping large numbers. This opens the door to atom-molecule sympathetic cooling and study of collisions. We are now working on spectroscopy of SrOH, leading up to co-trapping of SrOH and Li (or K). In addition, buffer gas cooling methods have been used and developed by the Ye, DeMille, and Lewandowski groups.

- Trapping and cooling

  Laser cooling in increasingly high dimensions has been accomplished by both the DeMille and Ye groups for SrF, TlF. Magnetic and magneto-optical trapping, often assisted by laser cooling in some dimension has been done for several species. This has been accomplished stepwise over the years, mostly one dimension at a

time, and increasingly combining the methods for best results. In addition, many of those efforts have been assisted by producing slow molecular beams with the help of the Doyle group. In general, with cooling methods, velocities of a few tens of m/s have been achieved. In addition, loading efficiency and densities have been approved, even to the extend that the Ye group has succeeded in evaporative cooling of OH.

- Stark deceleration

  New Stark deceleration techniques, mostly developed in the Lewandowski group but also by Ye and DeMille, allowed strong increases in molecular density. Various types of molecules were cooled in analog-controlled voltage Stark deceleration. In particular, in the Lewandowski group, Stark decelerated CH molecules were used for studies of ultracold chemistry.

- Indirect cooling

  First cooling atoms to ultracold temperatures and then associating them into molecules is one of the most versatile methods to produce ultracold molecules. This avenue has been followed by the groups of Eyler, Gould, and Stwalley (UConn expo) as well as the DeMille and Ye groups, often with theoretical support, notably by the Côté group and others. These efforts most importantly include magneto- and photoassociation of various molecules, such as KRb and RbCs. In addition, the Ketterle group has focused on producing LiNa this way, a molecule that is singled out by being the lightest bi-alkali molecule and thus having special properties such as chemical stability. Over the years, all these methods have been improved considerably, in particular with regard to volume, density, efficiency, selectivity of final states (e.g., production in to single hyperfine states). Since most of these molecules could not be studied in detail in the ultracold regime, extensive spectroscopic studies have been performed as well that should allow both, work based on those specification and easier spectroscopy of other molecules in the future. In addition, the UConn exp group has now started to study highly excited molecules, producing so-called trilobite states.

- Optical lattice ultracold polar molecules

  Polar molecules (KRb) can now be produced in a 3D optical lattice in the Ye lab and are studied for quantum information processing.

Collisions and Chemistry

- Calculations and specification

  The Kotochigova group performed extensive calculations to characterize general ultracold collisions and support experimental groups. This included state-dependent potential surfaces, collision cross sections, potential energies and dipole moments, effects of electric and magnetic fields, new resonances, long-range coefficients, effects of confinement, and dynamic polarizabilities for a large number of different molecules. These calculations always are the first starting point for experiments, and her group is close to have the world monopolies on these calculations. In addition, the Côté group has found (potentially generalizable) properties

of the KRb system such as chemical stability of the various combinations of the two species and in particular the often overlooked but important influence of higher order poles such as quadrupoles.

- Geometry and anisotropy

  The nature of anisotropic collisions and the use of direction-specific confinement was investigated by the Bohn and Ye groups. Reaction suppression and anisotropy was measured in different setups.

- Detection and spectroscopy

  In all experimental groups concerned with chemistry (JILA, Temple, Yale) spectroscopic identification methods have been improved as well as detection methods such as direct absorption imaging as well as . At UConn, this has in particular included the novel trilobite molecules.

- Control using electric/magnetic fields

  In the JILA groups, schemes were investigated to control the Stark shift of rotational states using lasers and electric fields. In addition, for OH, detailed studies were performed on the action of crossed electric and magnetic fields. Progress is being made with field-induced molecular collisions, state-selective molecular collisions, and quantum Zeno measurements of those.

- General collisions and universal properties

  The Bohn group has studied cold collisions in complex systems (Er, Dy,OH). including the prediction and characterization of novel long-lived resonance statesI In addition, they studied universal features among all dimers that can react at zero temperature. In addition, they found that ultracold collisions of alkali dimers may result in a novel "sticking" for milliseconds, with implications for trap stability etc., describable in the context of "quantum chaos." The Ketterle has found general universality and particular exception to it in LiNa collisions. Other groups have studied the properties of specific systems such as molecule collisions with pnictogen (Nitrogen) and a molecule (NH), NH_3 and OH (Doyle), theory of the benchmark system H_2+D (Côté), Rydberg dressing (Côté), Rb and Cs (DeMille), OH (Ye).

Quantum information and simulation.

This thrust has been mostly moved forward by the theoretical groups and, in the second half of the project, by the JILA lab. The main research here consisted of

- Quantum optics and quantum information with ultracold polar molecules

  In the Côté and Yelin groups, we proposed the use of Rydberg-mediated polar molecule interactions, methods to produce cluster states using dipolar interactions, and compared the use of polar molecules and ions for single photon nonlinearities, realistic quantum information processing schemes with molecular ions and anisotropic effects in opical lattices, cluster states in optical lattices, and a hybrid atom-molecule platform for quantum computing.

In addition, the Yelin group showed how ubiquitous cooperative effects (i.e., superradiance) is in ultracold molecular systems, in particular, their vibrational and lower-frequency transitions. and proceeded to study entanglement and spin squeezing in these systems, which can be considerable, both in ideal and in realistic systems. Collaborations with experiments have started recently.

– Dipolar many-body physics:

  Most of the theoretical work done in the Demler group concerns quantum simulations of many-body systems with (dipolar) interactions in single and multiple layers, such as exotic spin textures in magnetic superfluids, exotic paired states and Majorana fermions as well as Shiba states in fermionic superfluids, few-body bound states, impurities to find attractive polarons and manifestations of Anderson's orthogonality catastrophe, realizations of topological states using polar molecules on a lattice, studied the effect of dipole-dipole collisions on the transport properties in 2D many-body localization, a new class of unconventional critical phenomena characterized by singularities only in dynamical quantities, ways to experimentally probe such states and find new phases and resonances. This includes (i) systems of strongly interacting dipoles to study many-body localized phases, (ii) motion of an impurity particle injected with finite velocity into an interacting 1D quantum gas using large-scale numerical simulations, resulting in so-called *quantum flutter*; (iii) the dynamics of magnetic correlations in the half-filled fermionic Hubbard model following a fast ramp of repulsive interaction, leading to different dynamical behavior.

  The Yelin group has modeled quantum phases of quadrupolar particles, such as some homonuclear molecules, and are now studying quasi-1D and 2D many-body effects of particles with resonances due to in-plane dipole moments, with plans to investigate, in particular, the transition 1D $\rightarrow$ 2D, short range $\rightarrow$ long range interaction, and frustration.

– Experimental efforts with molecules in optical lattices

  The Ye/Jin group has realized a molecular spin lattice using dipolar exchange interactions in a 3D optical lattice, using it to study quantum magnetism and to compare to theories in this context. Encoding spin in rotational states, this led to observing spin exchanges of ultracold polar KRb molecules that are confined in a deep three-dimensional optical lattice. These observations were made in a regime where the lattice filling is dilute. Current experimental efforts are focused on increasing the filling fraction with plans to enable the study of richer physics, such as transport of excitations in an out of equilibrium long-range interacting system.

Molecular Ions

The Chuang group at MIT built an integrated on-chip superconducting ion trap for molecular ions. In particular, over the years, redesigned traps improved the major problem of charging dielectrics due to laser ablation in traps significantly thus demonstrating the trap. In addition, they performed detailed calculations for interfacing polar molecules with circuit QED systems and modeled photodissociation of molecular

ions, particularly $BaCl^+$ (with some help from DeMille). After another redesign, a new cryostat allows to increase microwave power to the superconducting trap chip, and a new chip design holds the ion 190 μm above the surface and thus increases the effective field strength. $BaCl^+$ serves as example on how we calculated electronic properties of dipolar ionic molecules, with focus on sympathetic cooling. A general method for rotational microwave spectroscopy and control of polar molecular ions via direct microwave addressing is considered, which would allow to make use of spatially varying AC Stark shifts, several unrelated factors led the group to abandon further development of the project.

A new project in the UConn experimental group has been started: they worked on the possibility of photoassociative ionization to form Rb_3+. This work will be continued with different support. In addition, in the Kotochigova group, electronic properties of molecular ions with a special view at sympathetic cooling have been performed.

Archival publications for the duration of the grant:

[1] M. Babadi and E. Demler. Collective excitations of quasi-two-dimensional trapped dipolar fermions: transition from collisionless to hydrodynamic regime. *Phys. Rev. A*, 86:063638, 2012.

[2] M. Babadi, B. Skinner, M. M. Fogler, and E. Demler. Universal behavior of repulsive two-dimensional fermions in the vicinity of the quantum freezing point. *Europhys. Lett.*, 103:16002, 2013.

[3] J. Banerjee, D. Rahmlow, R. Carollo, M. Bellos, E. E. Eyler, P. L. Gould, and W. C. Stwalley. Direct photoassociative formation of ultracold krb molecules in the lowest vibrational levels of the ground state. *Phys. Rev. A*, 86:053428, 2012.

[4] J. Banerjee, D. Rahmlow, R. Carollo, M. Bellos, E. E. Eyler, P. L. Gould, and W.C. Stwalley. Spectroscopy of the double minimum 3 $^3\pi_\omega$ electronic state of ^{39}k^{85}rb. *J. Chem. Phys.*, 138:164302, 2013.

[5] J. Banerjee, D. Rahmlow, R. Carollo, M. Bellos, E.E. Eyler, P.L. Gould, and W.C. Stwalley. Spectroscopy and applications of the 3 $^3\sigma^+$ electronic state of ^{3}9k^{8}5rb. *J. Chem. Phys.*, 139:174316, 2013.

[6] J. F. Barry, D. J. McCarron, E. B. Norrgard, M. H. Steinecker, and D. DeMille. Magneto-optical trapping of a diatomic molecule. *Nature*, 512:286–289, Aug 2014.

[7] J.F. Barry, E.S. Shuman, and D. DeMille. A bright, slow cryogenic molecular beam source for free radicals. *Phys. Chem. Chem. Phys*, in press, 2011.

[8] J.F. Barry, E.S. Shuman, E.B. Norrgard, and D. DeMille. Laser radiation pressure slowing of a molecular beam. *Phys. Rev. Lett.*, 100:103002, 2012.

[9] J. Bauer, M. Babadi, and E. Demler. Dynamical instabilities and transient short-range order in the fermionic hubbard model. arXiv:1411.4049, 2014.

[10] Johannes Bauer, Christophe Salomon, and Eugene Demler. Realizing a kondo-correlated state with ultracold atoms. *Phys. Rev. Lett.*, 111:215304, Nov 2013.

[11] M. A. Bellos, D. Rahmlow, R. Carollo, J. Banerjee, O. Dulieu, A. Gerdes, E. E. Eyler, P. L. Gould, and W. C. Stwalley. Formation of ultracold metastable rb_2 molecules in the $v = 0$ level of the a triplet σ_u + state by blue-detuned photoassociation to the 1 triplet π_g state. *Phys. Chem. Chem. Phys. (special issue on Ultracold Molecules)*, 13:18880, 2011.

[12] M.A. Bellos, R. Carollo, J. Banerjee, M. Ascoli, A.-R. Allouche, E. E. Eyler, P. L. Gould, and W. C. Stwalley. Upper bound to the ionization energy of $^{85}rb_2$. *Phys. Rev. A*, 87:012508, 2013.

[13] M.A. Bellos, R. Carollo, J. Banerjee, E.E. Eyler, P.L. Gould, and W.C. Stwalley. Excitation of ultracold molecules to trilobite-like rydberg states. *PRL*, 111:053001, 2013.

[14] M.A. Bellos, R. Carollo, D. Rahmlow, J. Banerjee, E.E. Eyler, P.L. Gould, and W.C. Stwalley. Photoassociation to the 2 $^1\sigma_g^+$ state in ultracold rb_2 in the presence of a shape resonance. *Phys. Rev. A*, 86:033407, 2012.

[15] M.A. Bellos, D. Rahmlow, R. Carollo, J. Banerjee, O. Dulieu, A. Gerdes, E.E. Eyler, P.L. Gould, and W.C. Stwalley. Formation of ultracold Rb_2 molecules in the v"=0 level of the a triplet Σ_u^+ state via blue-detuned photoassociation to the $1^3\Pi_g$ state. *Phys. Chem. Chem. Phys. (Special Issue on Ultracold Molecules)*, 13:18880, 2011 *.

[16] S. G. Bhongale, L. Mathey, Erhai Zhao, S. F. Yelin, and Mikhail Lemeshko. Quantum phases of quadrupolar fermi gases in optical lattices. *Phys. Rev. Lett.*, 110:155301, 2013.

[17] John L. Bohn and Goulven Quéméner. Dipolar radicals in crossed electric and magnetic fields. *Molecular Physics*, 111:00268976.2013.783721, 2013.

[18] C D Bruzewicz, Mattias Gustavsson, Toshihiko Shimasaki, and D DeMille. Continuous formation of vibronic ground state rbcs molecules via photoassociation. *New Journal of Physics*, 16(2):023018, 2014.

[19] Jason N. Byrd and Robin Côté. Formation of ultracold tetramers by photoassociation of bi-alkali dimers. in preparation (to be submitted to PRL), 2013.

[20] Jason N. Byrd, Robin Côté, and Jr John A. Montgomery. Long-range interactions between like homonuclear alkali metal diatoms. *J. Chem. Phys.*, 135:244307, 2011.

[21] Jason N. Byrd, H. Harvey Michels, Jr. John A. Montgomery, Robin Côté, and William C. Stwalley. Structure, energetics, and reactions of alkali tetramers. *J. Chem. Phys.*, 136:014306, 2012.

[22] Jason N. Byrd, John A. Montgomery, and R. Côté. Structure and thermochemistry of $k_2$rb, krb$_2$, and $k_2$rb$_2$. *Phys. Rev. A*, 82(1):010502, Jul 2010.

[23] R. Carollo, M.A. Bellos, D. Rahmlow, J. Banerjee, E. E. Eyler, P. L. Gould, and W. C. Stwalley. Observation and analysis of resonant coupling between near-degenerate levels of the $2^1\sigma_g^+$ and $1^1\pi_g$ states of ultracold ^{85}rb$_2$. *Phys. Rev. A*, 87:022505,, 2013.

[24] Ching-Kit Chan, Guin-Dar Lin, Susanne F. Yelin, and Mikhail D. Lukin. Quantum interference between independent reservoirs in open quantum systems. *Phys. Rev. A*, 89:042117, Apr 2014.

[25] K. Chen, S. J. Schowalter, S. Kotochigova, A. Petrov, W. G. Rellergert, S. T. Sullivan, and E. R. Hudson. Molecular-ion trap-depletion spectroscopy of $BaCl^+$. *Phys. Rev. A*, 83:030501(R), 2011 *.

[26] R. W. Cherng and E. Demler. Neutral skyrmion configurations in the low-energy effective theory of spinor-condensate ferromagnets. *Phys. Rev. A*, 83:053614, 2011.

[27] R. W. Cherng and E. Demler. Symmetry analysis of crystalline spin textures in dipolar spinor condensates. *Phys. Rev. A*, 83:053613, 2011.

[28] A. Choatia, B. Neyenhuis, S. Moses, B. Yan, J. P. Covey, M. Foss-Feig, A. M. Rey, D. S. Jin, and J. Ye. Long-lived dipolar molecules and feshbach molecules in a 3d optical lattice. *Phys. Rev. Lett.*, 108:080405, 2012.

[29] Caleb Christensen. Ultracold molecules from ultracold atoms: Interactions in sodium and lithium gas. *Ph.D. Thesis, MIT*, 2011.

[30] A. L. Collopy, M. T. Hummon, M. Yeo, B. Yan, and J. Ye. Prospects for a narrow line mot in yo. in press, 2015.

[31] J. F. E. Croft and J. L. Bohn. Long-lived complexes and chaos in ultracold molecular collisions. *PRA*, 89:012714, 2014.

[32] J. F. E. Croft and J. L. Bohn. Non-sticking of helium buffer gas to hydrocarbons. *Phys. Rev. A*, 91:032706, 2015.

[33] M. H. G. de Miranda, A. Choatia, B. Neyenhuis, D. Wang, G. Qumner, S. Ospelkaus, J. L. Bohn, J. Ye, and D. S. Jin. Controlling the quantum stereodynamics of ultracold bimolecular reactions. *Nature Physics*, 7:502, 2011.

[34] D. DeMille, J. F. Barry, E. R. Edwards, E. B. Norrgard, and M. H. Steinecker. On the transverse confinement of radiatively slowed molecular beams. *Molecular Physics*, 111:1, 2013.

[35] M. I. Fabrikant, Tian Li, N. J. Fitch, N. Farrow, Jonathan D. Weinstein, and H. J. Lewandowski. Method for traveling-wave deceleration of buffer-gas beams of ch. *Phys. Rev. A*, 90:033418, Sep 2014.

[36] N.J. Fitch, D.A. Esteves, M.I. Fabrikant, T.C. Briles, Y. Shyur, L.P. Parazzoli, and H.J. Lewandowski. State purity of decelerated molecular beams. *Journal of Molecular Spectroscopy*, 278:1, 2012.

[37] A. Frisch, M. Kiyotaka, F. Ferlaino, J. L. Bohn, C. Makrides, A. Petrov, and S. Kotochigova. Quantum chaos in ultracold collisions of erbium. *Nature*, 507:475, 2014.

[38] Sarang Gopalakrishnan, Ivar Martin, and Eugene A. Demler. Quantum quasicrystals of spin-orbit-coupled dipolar bosons. *Phys. Rev. Lett.*, 111:185304, Oct 2013.

[39] A. V. Gorshkov, S. R. Manmana, G. Chen, J. Ye, E. Demler, M. D. Lukin, and A. M. Rey. Tunable superfluidity and quantum magnetism with ultracold polar molecules. *Phys. Rev. Lett.*, 107:115301, 2011 *.

[40] Alexey V. Gorshkov, Salvatore R. Manmana, Gang Chen, Eugene Demler, Mikhail D. Lukin, and Ana Maria Rey. Quantum magnetism with polar alkali-metal dimers. *Phys. Rev. A*, 84:033619, Sep 2011.

[41] K. R. A. Hazzard, B. Gadway ND M. Foss-Feig, B. Yan, S. A. Moses, J. P. Covey, N. Y. Yao, M. D. Lukin, J. Ye, D. S. Jin, and A. M. Rey. Many-body dynamics of dipolar molecules in an optical lattice. *Phys. Rev. Lett.*, 113:195302, 2014.

[42] Myoung-Sun Heo, Tout T. Wang, Caleb A. Christensen, Timur M. Rvachov, Dylan A. Cotta, Jae-Hoon Choi, Ye-Ryoung Lee, and Wolfgang Ketterle. Formation of ultracold fermionic nali feshbach molecules. *Phys. Rev. A*, 86:021602, Aug 2012.

[43] M. T. Hummon, M. Yeo, B. K. Stuhl, A. L. Collopy, Y. Xia, and J. Ye. 2d magneto-optical trapping of diatomic molecules. *Phys. Rev. Lett.*, 110:143001, 2013.

[44] L.R. Hunter, S.K. Peck, A.S. Greenspon, S.S. Alam, and D. DeMille. Prospects for laser cooling tlf. *Phys. Rev. A*, 85:012511, 2012.

[45] N.R. Hutzler, Hsin-I Lu, and J.M. Doyle. Buffer gas cooling and intense, cold, slow molecular beams. *Chem. Rev. (Special Issue on Ultracold Molecules)*, 112:4803, 2012.

[46] Z. Idziasek, G. Quemener, J. L. Bohn, and P. S. Julienne. A simple model of ultracold polar molecule collisions. *Phys. Rev. A*, 82:020702(R), 2010.

[47] Z. Idziaszek, G. Quéméner, J. L. Bohn, and P. S. Julienne. A simple quantum model of ultracold polar molecule collisions. *Phys. Rev. A*, 82:020703(R), 2010.

[48] Jr. Jason N. Byrd, H. John A. Montgomery, and Robin Côté. Controllable binding of polar molecules and metastability of one-dimensional gases with attractive dipole forces. *Phys. Rev. Lett.*, 109:083003, 2012.

[49] Jr. Jason N. Byrd, H. John A. Montgomery, and Robin Côté. Long range forces between polar alkali diatoms aligned by external electric fields. *Phys. Rev. A*, 86:032711, 2012.

[50] Liang Jiang, Takuya Kitagawa, Jason Alicea, A. R. Akhmerov, David Pekker, Gil Refael, J. Ignacio Cirac, Eugene Demler, Mikhail D. Lukin, and Peter Zoller. Majorana fermions in equilibrium and driven cold atom quantum wires. *Phys.Rev.Lett.*, 106:220402, 2011.

[51] D. S. Jin and J. Ye. Polar molecules in the quantum regime. *Physics Today*, 64:27, 2011. invited review.

[52] D. S. Jin and J. Ye. Introduction to ultracold molecules: New frontiers in quantum and chemical physics. *Chemical Reviews*, 112:4801, 2012.

[53] M. Kanász-Nagy, E. A. Demler, and G. Zaránd. Theory of confinement-induced interlayer molecular resonances. *ArXiv e-prints*, January 2014.

[54] J.-T. Kim, B. Kim, and W.C. Stwalley. *Spectroscopic Analysis of the Alkali Metal Diatomic Molecules Using Both Molecular Beam and Ultracold Molecule Experiments.* in "Molecular Beams: State of the Art 2014", Springer, 2014.

[55] J.T. Kim, B. Kim, and W.C. Stwalley. *Analysis of Alkali Metal Diatomic Spectra: Using Molecular Beams and Ultracold Molecules.* ebook (Institute of Physics Series in Concise Physics), 2014.

[56] J.T. Kim, Y. Lee, B. Kim, D. Wang, W.C. Stwalley, P.L. Gould, and E.E. Eyler. Spectroscopic analysis of the coupled $1^1\Pi$, $2^3\Sigma^+(\Omega = 0^-, 1)$, and $\mathrm{b}^3\Pi(\Omega = 0^{+/-}, 1, 2)$ states of the KRb molecule using both ultracold molecule and molecular beam experiments. *Phys. Chem. Chem. Phys. (Special Issue on Ultracold Molecules)*, 13:18755, 2011 *.

[57] J.T. Kim, Y. Lee, B. Kim, D. Wang, W.C. Stwalley, P.L. Gould, and E.E. Eyler. Spectroscopic prescription for optimal stimulated raman transfer of ultracold heteronuclear molecules to the lowest rovibronic level. *Phys. Rev. A*, 84:062511, 2011.

[58] J.T. Kim, Y. Lee, B. Kimand D. Wang, P. L. Gould, E. E. Eyler, and W.C. Stwalley. Spectroscopic investigation of the a and 3 $^1\sigma_+$ states of $^{39}\mathrm{k}^{85}\mathrm{rb}$. *J. Chem. Phys.*, 137:244301, 2012.

[59] M. Knap, E. Berg, M. Ganahl, and E. Demler. Clustered wigner crystal phases of cold polar molecules in arrays of one-dimensional tubes. Phys. Rev. B in print (arXiv:1112.5662), 2012.

[60] M. Knap and andE. Demler D. Abanin. Dissipative dynamics of a driven quantum spin coupled to a non-markovian bath of ultracold fermions. *Phys. Rev. Lett.*, 111:265302, 2013.

[61] M. Knap, C. Mathy, M. Zvonarev, and E. Demler. Quantum flutter: Signatures and robustness. *Phys. Rev. Lett.*, 112:015302, 2014.

[62] M. Knap, A. Shashi, Y. Nishida, A. Imambekov, D. Abanin, and E. Demler. Time dependent impurity in ultracold fermions: orthogonality catastrophe and beyond. arXiv:1206.4962, 2012.

[63] Michael Knap, Adrian Kantian, Thierry Giamarchi, Immanuel Bloch, Mikhail D. Lukin, and Eugene Demler. Probing real-space and time-resolved correlation functions with many-body ramsey interferometry. *Phys. Rev. Lett.*, 111:147205, Oct 2013.

[64] S. Kotochigova. Dispersion interactions and reactive collisions of ultracold polar molecules. *New J. Phys.*, 12:073041, 2010.

[65] S. Kotochigova. Controlling interactions between highly-magnetic atoms with feshbach resonances. *Rep. Prog. Phys.*, 77:093901, 2014. (Review Article).

[66] S. Kotochigova and D. DeMille. Electric-field-dependent dynamic polarizability and state-insensitive conditions for optical trapping of diatomic polar molecules. *Phys. Rev. A*, 82:063421, 2010.

[67] S. Kotochigova, A. Petrov, M. Linnik, J. Klos, and P. S. Julienne. Ab initio properties of Li-group-II molecules for ultracold matter studies. *J. Chem. Phys.*, 135:164108, 2011.

[68] I. Kozyryev, L. Baum, K. Matsuda, P. Olson, B. Hemmerling, and J.M. Doyle. Collisional relaxation of vibrational states of sroh with he at 2k. *New Journal of Physics*, 17:045003, 2015.

[69] Elena Kuznetsova, T. Bragdon, Robin Côté, and S. F. Yelin. Cluster-state generation using van der Waals and dipole-dipole interactions in optical lattices. *Phys. Rev. A*, 85:012328, 2012.

[70] Elena Kuznetsova, Robin Côté, and Susanne Yelin. *Coherent laser manipulation of ultracold molecules*, page 53. in "Femtosecond Optics," Intech, 2011 *.

[71] Elena Kuznetsova, Seth T. Rittenhouse, Hossein R. Sadeghpour, and S. F. Yelin. Rydberg atom mediated polar molecule interactions: a tool for molecular-state conditional quantum gates and individual addressability. *Phys. Chem. Chem. Phys.*, 13:17115, 2011 *.

[72] Elena Kuznetsova, S. F. Yelin, and Robin Côté. An atom-molecule platform for quantum computing. *Quantum Inf. Proc.*, 10:821838, 2011.

[73] L. Lamata, D. R. Leibrandt, I. L. Chuang, J. I. Cirac, M. D. Lukin, V. Vuletic, and S. F. Yelin. Ion crystal transducer for strong coupling between single ions and single photons. *Phys. Rev. Lett.*, 107:030501, 2011.

[74] M. Lemeshko, R.V. Krems, J.M. Doyle, and S. Kais. Manipulation of molecules with electromagnetic fields. *Molecular Physics*, 111:1648, 2013.

[75] Rui Li, Elie Wolfe, and S.F. Yelin. Spin squeezing by means of driven superradiance. in preparation, previous version: arXiv:1405.5288, 2015.

[76] G.-D. Lin and S. F. Yelin. Correlation in superradiance: A closed-form approach. *Adv. Atom. Mol. Opt. Phys.*, 61:253, 2012. chapter 6.

[77] G.-D. Lin and S. F. Yelin. Superradiance in spin-j particles: Effects of multiple levels. *Phys. Rev. A*, 85:033831, Mar 2012.

[78] G.-D. Lin and S. F. Yelin. Vibrational spectroscopy of polar molecules with superradiance. *Molecular Physics*, 111:00268976.2013.803167, 2013.

[79] Hsin-I Lu, I. Kozyryev, B. Hemmerling, J. Piskorski, and J.M. Doyle. Magnetic trapping of molecules via optical loading and magnetic slowing. *PRL*, 112:113006, 2014.

[80] Hsin-I Lu, J. Rasmussen, M.J. Wright, D. Patterson, and J.M. Doyle. A cold and slow molecular beam. *Phys. Chem. Chem. Phys.*, 12:18986, 2011.

[81] MIchael Mayle, Goulven Quéméner, Brandon Ruzic, and John L. Bohn. Scattering of ultracold molecules in the highly resonant regime. *Phys. Rev. A*, 87:01270, 2013.

[82] D J McCarron, E B Norrgard, M H Steinecker, and D DeMille. Improved magneto-optical trapping of a diatomic molecule. *New Journal of Physics*, 17(3):035014, 2015.

[83] B. Neyenhuis, B. Yan, S. A. Moses, J. P. Covey, A. Chotia, A. Petrov, S. Kotochigova, J. Ye, and D. S. Jin. Polarizability of ultracold polar 40k87rb molecule. *Phys. Rev. Lett.*, 109:230403, 2012.

[84] K.-K. Ni, S. Ospelkaus, D. Wang, G. Quéméner, B. Neyenhuis, M. H. G. de Miranda, J. L. Bohn, J. Ye, and D. S. Jin. Dipolar collisions of polar molecules in the quantum regime. *Nature*, 464:1324, 2010.

[85] S. Ospelkaus, K.-K. Ni, G. Quéméner, B. Neyenhuis, D. Wang, M. H. G. de Miranda, J. L. Bohn, J. Ye, and D. S. Jin. Controlling the hyperfine state of rovibronic ground-state polar molecules. *Phys. Rev. Lett.*, 104:030402, 2010.

[86] S. Ospelkaus, K.-K. Ni, D. Wang, M. H. G. de Miranda, B. Neyenuis, G. Quéméner, P. S. Julienne, J. L. Bohn, D. S. Jin, and J. Ye. Quantum-state controlled chemical reactions of ultracold potassium-rubidium molecules. *Science*, 327:853, 2010.

[87] Johannes Otterbach, Qingyang Wang, Niraj Ghimire, and S. F. Yelin. Quantum phases of externally in-plane polarized hard-core dipoles on a zig-zag chain with simultaneous attractive and repulsive interactions. in preparation, 2015.

[88] L. P. Parazzoli, N. J. Fitch, P. S. Zuchowski, J. M. Hutson, and H. J. Lewandowski. Large effects of electric fields on atom-molecule collisions at millikelvin temperatures. *Phys. Rev. Lett.*, 106:193201, 2011.

[89] D. Patterson, E.Tsikita, and J.M. Doyle. Cooling and collisions of large gas phase molecules. *PCCP*, 12:9736, 2010.

[90] David Pekker, Gil Refael, Ehud Altman, Eugene Demler, and Vadim Oganesyan. Hilbert-glass transition: New universality of temperature-tuned many-body dynamical quantum criticality. *Phys. Rev. X*, 4:011052, Mar 2014.

[91] V. Pietilä, D. Pekker, Y. Nishida, and E. Demler. Pairing instabilities in quasi-two-dimensional fermi gases. *Phys. Rev. A*, 85:023621, 2012.

[92] G. Quéméner and J. L. Bohn. Electric field suppression of ultracold confined chemical rates. *Phys. Rev. A*, 81:060701(R), 1–4, 2010.

[93] G. Quemener and J. L. Bohn. Electric-field suppression of ultracold confined chemical rates. *Phys, Rev. A*, 81:060701(R), 2010.

[94] G. Quéméner and J. L. Bohn. Strong dependence of ultracold chemical rates on electric dipole moments. *Phys. Rev. A*, 81:022702, 1–9, 2010.

[95] G. Quéméner and J. L. Bohn. Dynamics of ultracold molecules in confined geometry and electric field. *Phys. Rev. A*, 83:012705, 2011.

[96] G. Quéméner, J. L. Bohn, A. Petrov, and S. Kotochigova. Universalities in ultracold reactions of alkali polar molecules. *Phys. Rev. A*, 84:062703, 2011.

[97] G. Quéméner and P. S. Julienne. Ultracold molecules under control! *Chem. Rev. (Special Issue on Ultracold Molecules)*, 112:4949, 2012.

[98] Goulven Quéméner and John L. Bohn. Ultracold molecular collisions in combined electric and magnetic fields. *Phys. Rev. A*, 88:012706, 2013.

[99] S. Sainis, J. Sage, E. Tiesinga, S. Kotochigova, T. Bergeman, and D. DeMille. Detailed spectroscopy of the cs_2 $a\,^3\sigma_u^+$ state and implications for measurements sensitive to variation of the electron-proton mass ratio. *Phys. Rev. A*, 86:022513, 2012.

[100] B. C. Sawyer, B. K. Stuhl, M. Yeo, T. V. Tscherbul, M. T. Hummon, Y. Xia, J. Klos, D. Patterson, J. M. Doyle, and J. Ye. Cold heteromolecular dipolar collisions. *Phys. Chem. Chem. Phys. (Special Issue on Ultracold Molecules)*, 13:19059, 2011 *.

[101] R. Schmidt, T. Enss, V. Pietilä, and E. Demler. Fermi polarons in two dimensions. *Phys. Rev. A*, 85:021602, 2012.

[102] D. I. Schuster, Lev S. Bishop, I. L. Chuang, D. DeMille, and R. J. Schoelkopf. Cavity QED in a molecular ion trap. *Phys. Rev. A*, 83(1):012311, Jan 2011.

[103] Aditya Shashi, Fabian Grusdt, Dmitry A. Abanin, and Eugene Demler. Radio-frequency spectroscopy of polarons in ultracold bose gases. *Phys. Rev. A*, 89:053617, May 2014.

[104] M. Shi, P. F. Herskind, M. Drewsen, and I. L. Chuang. Microwave quantum logic spectroscopy and control of molecular ions. (submitted), 2013.

[105] Toshihiko Shimasaki, Michael Bellos, C. D. Bruzewicz, Zack Lasner, and David DeMille. Production of rovibronic-ground-state rbcs molecules via two-photon-cascade decay. *Phys. Rev. A*, 91:021401, Feb 2015.

[106] E. S. Shuman, J. F. Barry, and D. DeMille. Laser cooling of a diatomic molecule. *Nature*, 467:820, 2010.

[107] E. S. Shuman, J. F. Barry, D. R. Glenn, and D. DeMille. Radiative force from optical cycling on a diatomic molecule. *Phys. Rev. Lett.*, 103:223001, 2009.

[108] B. K. Stuhl, M. T. Hummon, and J. Ye. Cold state-selected molecular collisions and reactions. *Annu. Rev. Phys. Chem.*, 65:501, 2014.

[109] B. K. Stuhl, M. T. Hummon, M. Yeo, G. Quéméner, J. L. Bohn, and J. Ye. Evaporative cooling of the dipolar radical oh. *Nature*, 492:396, 2012.

[110] B. K. Stuhl, M. Yeo, M. T. Hummon, and J. Ye. Electric-field-induced inelastic collisions between magnetically trapped hydroxyl radicals. *Molecular Physics*, 111:00268976.2013.793838, 2013.

[111] B. K. Stuhl, M. Yeo, B. C. Sawyer, M. T. Hummon, and J. Ye. Microwave state transfer and adiabatic dynamics of magnetically trapped polar molecules. *Phys. Rev. A*, 85:033427, 2012.

[112] W. C. Stwalley. Theory and spectroscopy for ultracold krb molecules. volume 1504 of *AIP Conference Proceedings*, page 509, 2012.

[113] W.C. Stwalley, M. Bellos, R. Carollo, J. Banerjee, and M. Bermudez. Shortcuts for understanding rovibronic spectroscopy of ultracold alkali metal diatomic molecules. *Molecular Physics*, 110:1739, 2012.

[114] A. G. Sykes and J. L. Bohn. Noneqiulibrium dynamics of an ultracold dipolar gas. *Phys. Rev. A*, 91:013615, 2015.

[115] Tetsu Takekoshi, Markus Debatin, Raffael Rameshan, Francesca Ferlaino, Rudolf Grimm, Hanns-Christoph Nägerl, C. Ruth Le Sueur, Jeremy M. Hutson, Paul S. Julienne, Svetlana Kotochigova, and Eberhard Tiemann. Towards the production of ultracold ground-state rbcs molecules: Feshbach resonances, weakly bound states, and the coupled-channel model. *Phys. Rev. A*, 85:032506, 2012.

[116] S. Truppe, R.J. Hendricks, S.K. Tokunaga, H.J. Lewandowski, M.G. Kozlov, C. Henkel, E.A. Hinds, and M.R. Tarbutt. A search for varying fundamental constants using hertz-level frequency measurements of cold ch molecules. *Nature Communications*, 4:2600, 2013.

[117] Eric Vernier, David Pekker, Martin W. Zwierlein, and Eugene Demler. Bound states of a localized magnetic impurity in a superfluid of paired ultracold fermions. *Phys. Rev. A*, 83:033619, 2011.

[118] D. Wang, B. Neyenhuis, M. H. G. de Miranda, K.-K. Ni, S. Ospelkaus, D. S. Jin, and J. Ye. Direct absorption imaging of ultracold polar molecules. *Phys. Rev. A*, 81:061404(R), 2010.

[119] Jia Wang, Jason N. Byrd, Ion Simbotin, and R. Côté. Tuning ultracold chemical reactions via rydberg-dressed interactions. *Phys. Rev. Lett.*, 113:025302, Jul 2014.

[120] Shannon X. Wang, Yufei Ge, Jaroslaw Labaziewicz, Eric Dauler, Karl Berggren, and Isaac L. Chuang. Superconducting microfabricated ion traps. *Appl. Phys. Lett.*, 97(244102), 2010.

[121] T. T. Wang, M.-S. Heo, T. M. Rvachov, D. A. Cotta, and W. Ketterle. Deviation from universality in collisions of ultracold ^{6}li$_2$ molecules. *Phys. Rev. Lett.*, 110:173203, 2013.

[122] Elie Wolfe and S. F. Yelin. Certifying separability in symmetric mixed states of n qubits, and superradiance. *Phys. Rev. Lett.*, 112:140402, Apr 2014.

[123] B. Wunsch, N. T. Zinner, I. B. Mekhov, S.-J. Huang, D.-W. Wang, and E. Demler. Few-body bound states in dipolar gases and their detection. *Phys. Rev. Lett.*, in press, 2011.

[124] B. Yan, S. A. Moses, B. Gadway, J. P. Covey, K. R. A. Hazzard, A. M. Rey, D. S. Jin, and J. Ye. Observation of dipolar spin-exchange interactions with lattice-confined polar molecules. *Nature*, 501:521, 2013.

[125] N. Yao, C. Laumann, S. Gopalakrishnan, M. Knap, M. Mueller, E. Demler, and M. Lukin. Many-body localization in dipolar systems. *Phys. Rev. Lett.*, 113:243002, 2014.

[126] N. Yao, C. Laumann, A. Gorshkov, S. Bennett, E. Demler, P. Zoller, and M. D. Lukin. Topological flat bands from dipolar spin systems. *Phys. Rev. Lett.*, 109:266804, 2012.

[127] N. Y. Yao, A. V. Gorshkov, C. R. Laumann, A. Läuchli, J. Ye, and M. D. Lukin. Realizing fractional chern insulators with dipolar spins. *Phys. Rev. Lett.*, 110:185302, 2013.

[128] J. Ye and D. S. Jin. Polar molecules near quantum degeneracy. In H. Katori, H. Yoneda, K. Nakagawa, and F. Shimizu, editors, *Laser Spectroscopy XIX*, pages 247 – 255. World Scientific, Singapore, 2010.

[129] M. Yeo, M. T. Hummon, A. L. Collopy, B. Yan, B. Hemmerling, E. Chae, J. M. Doyle, and J. Ye. Rotational state microwave mixing for laser cooling of complex diatomic molecules. submitted, 2015.

[130] B. Zhu, B. Gadway, M. Foss-Feig, J. Schachenmayer, M. L. Wall, K. R. A. Hazzard, B. Yan, S. A. Moses, J. P. Covey, D. S. Jin, J. Ye, M. Holland, and A. M. Rey. Suppressing the loss of ultracold molecules via the continuous quantum zeno effect. *PRL*, 112:070404, 2014.

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